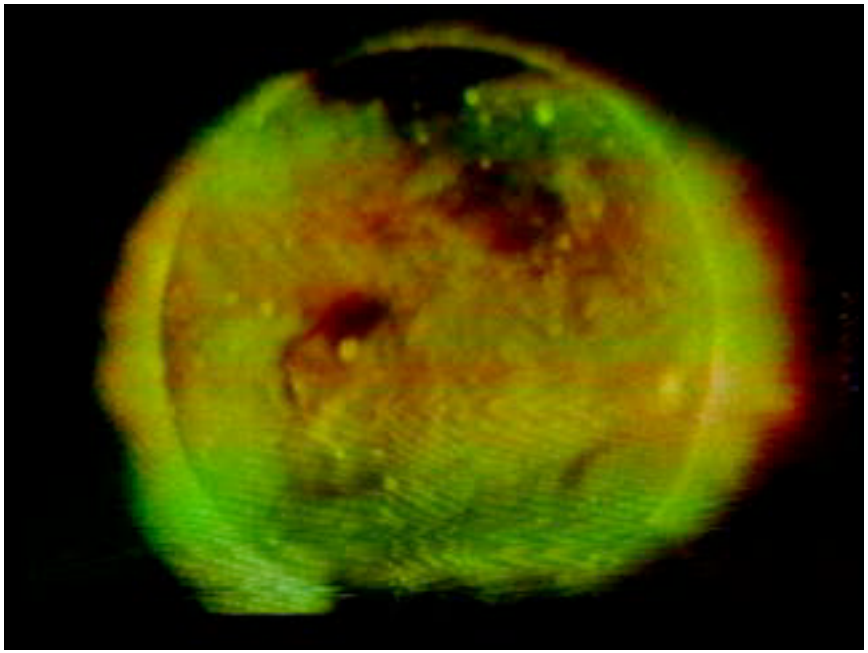
Coronal Holes and SWx

Michael S.F. Kirk

[NASA GSFC | ASTRA]

Hole-y Corona!



Skylab's Apollo Telescope Mount x-ray images from June 1973 revolutionized high temperature solar imagery.

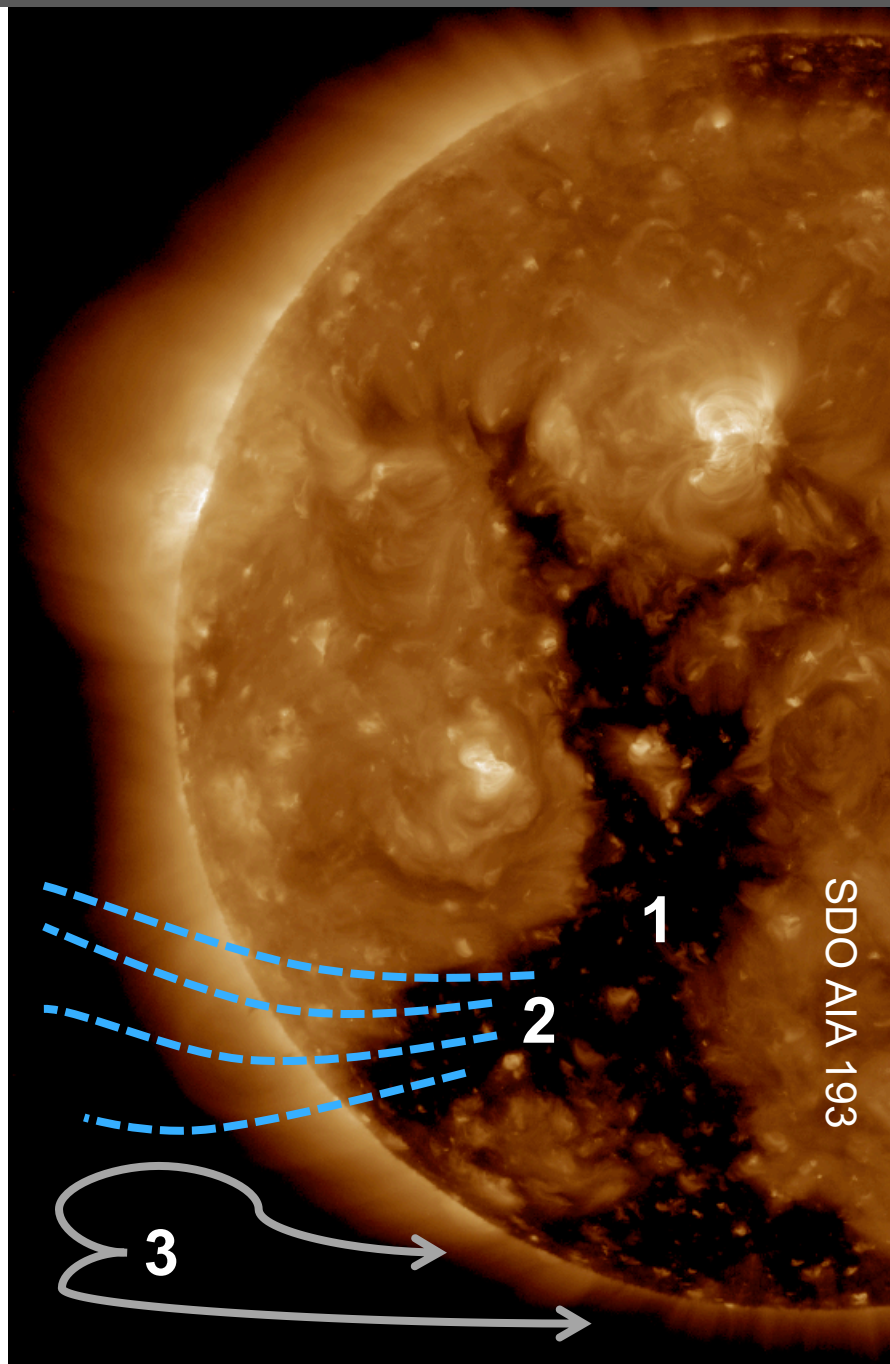
These are the first images that conclusively discovered low density, dark patches in the solar corona.

Waldmeier is the modern discoverer of coronal holes in 1957. However it wasn't until photographs of the Sun from above the Earth's atmosphere, they were identified as 3D structures in their own right.

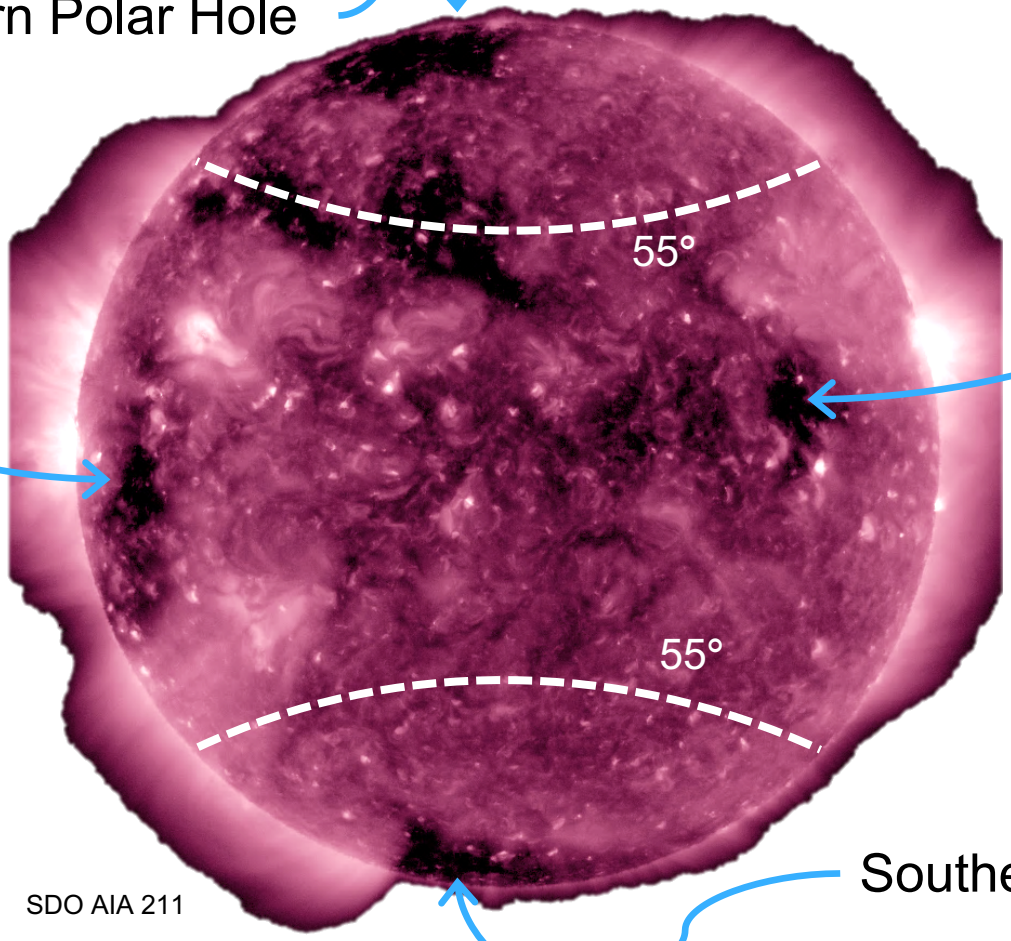
A Vacant Corona

"Coronal holes" simultaneously refer to three different phenomena:

1. Dark patches in x-ray or EUV images representing a lack of emitting coronal plasma.
2. "Open" magnetic field lines emanating from the solar surface.
3. Low emission off the limb of the sun.

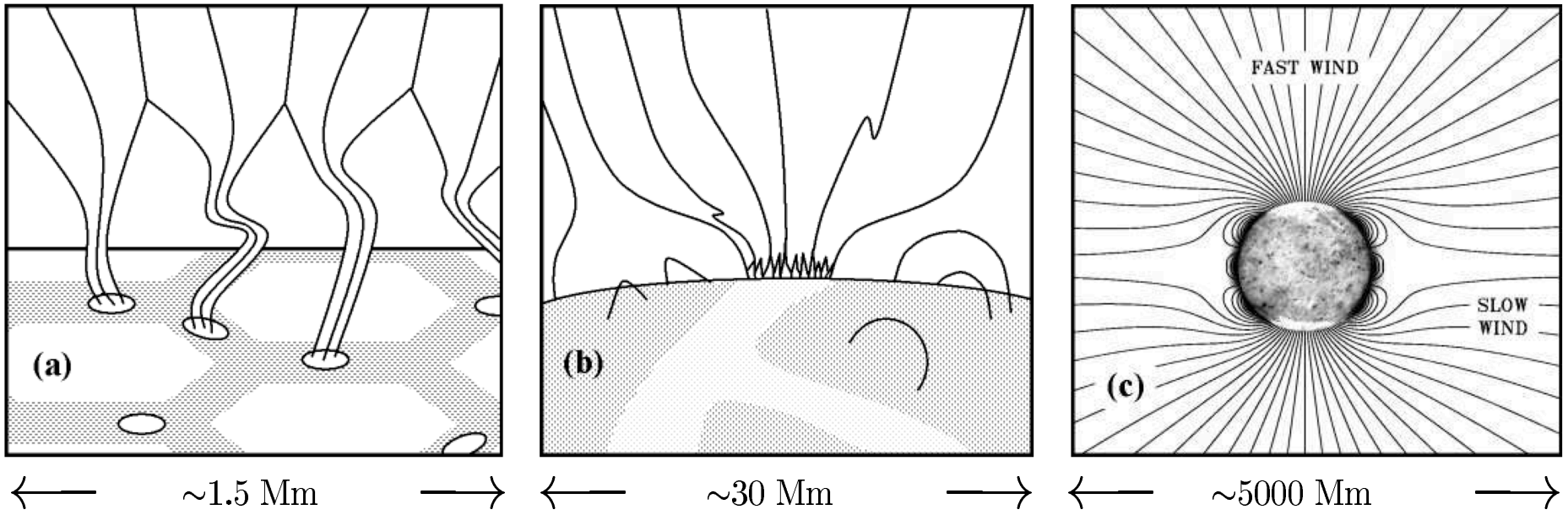


Dark Patches: Coronal Hole Zoology



Current observations are made in X-ray and EUV (and He I Triplet).

Open Field Lines: Coronal Hole Theory

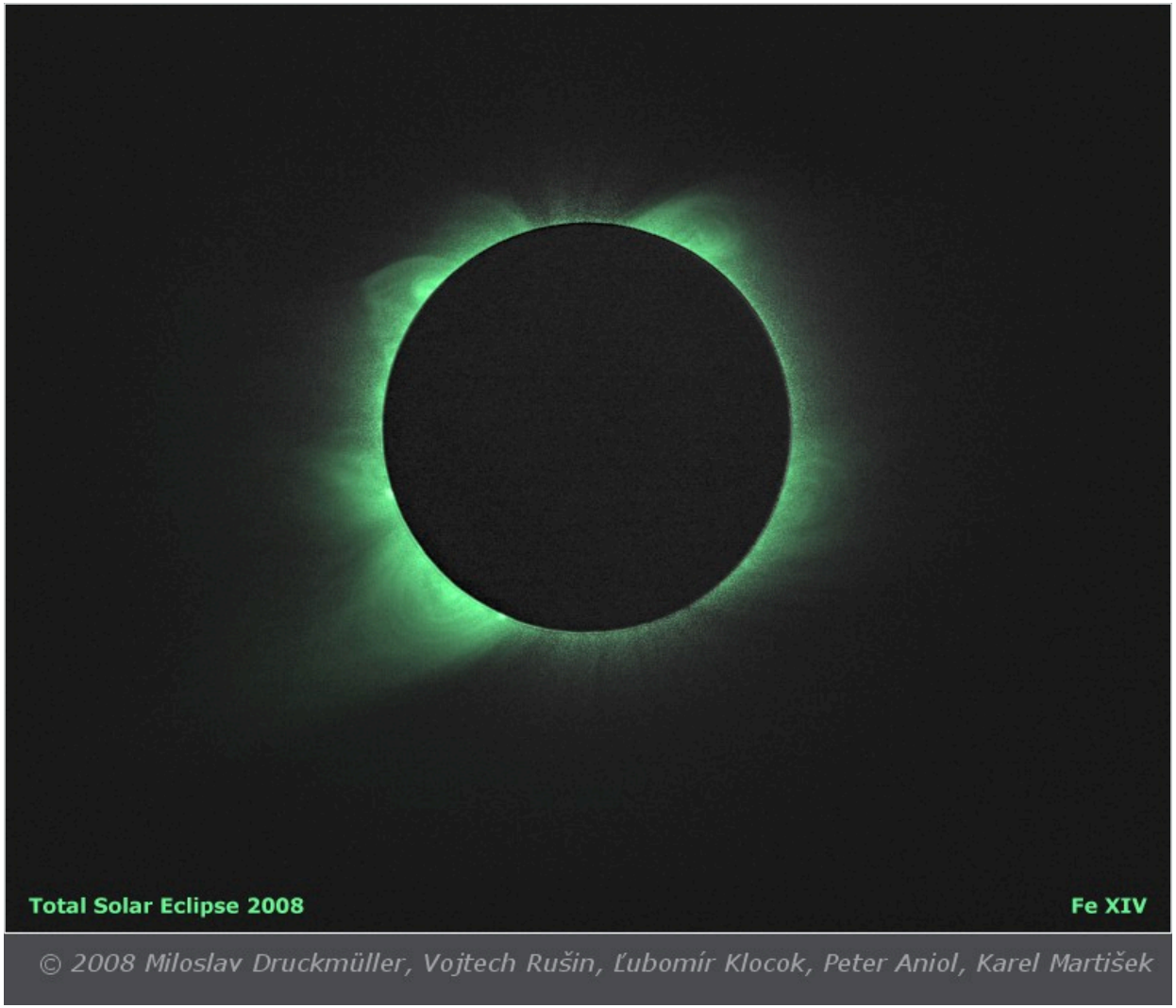


Cranmer and van Ballegooijen (2005)

a) Magnetic field lines organize in the inter-granular lanes as flux tubes.
b) A fraction of these lines organize in the lanes of supergranules.
c) Large mono-polar regions extend into the corona and are ‘open.’

Megameter (Mm) = 1,000,000 m

Low Emission: Ground-based Imaging

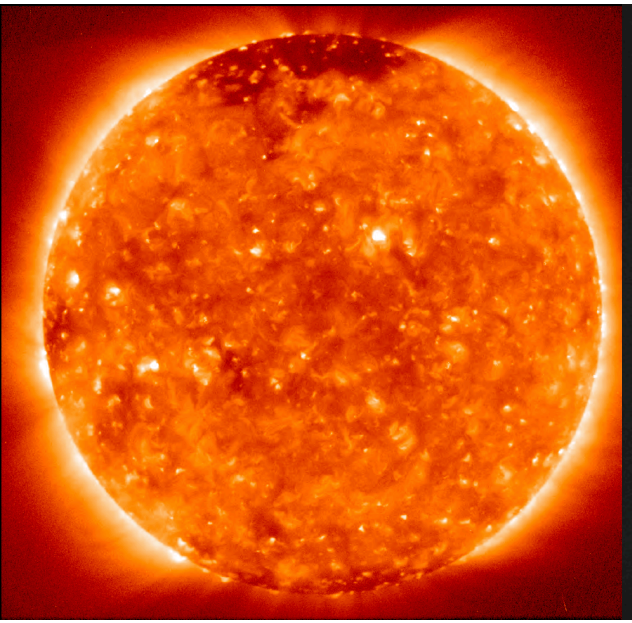


530.3 nm “Green line” images from natural or man-made eclipses were the only observations of coronal holes until the space age.

These images are rarely used in modern coronal hole studies but are an essential link to historic datasets.

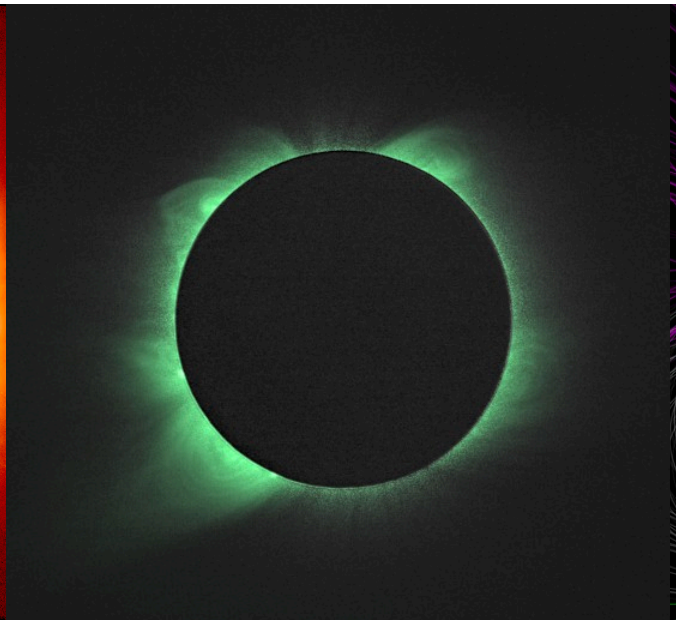
A less-than-solved problem…

EUV X-Ray Images



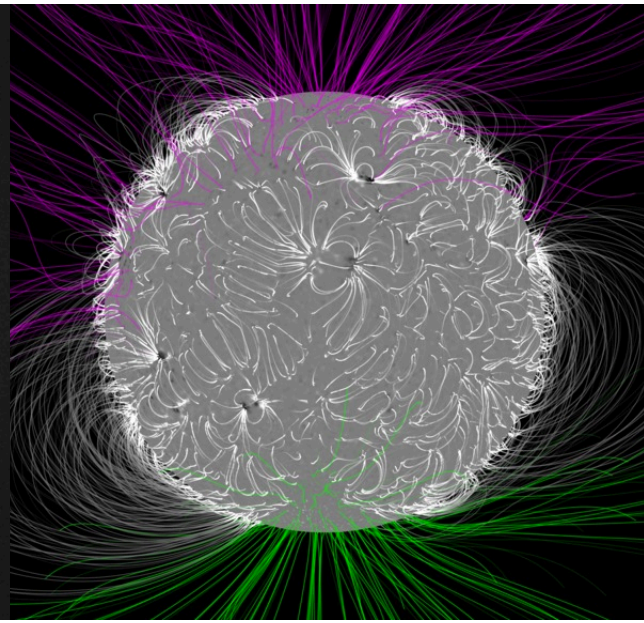
Hinode XRT

Ground-based Observations



Druckmüller, Fe XIV

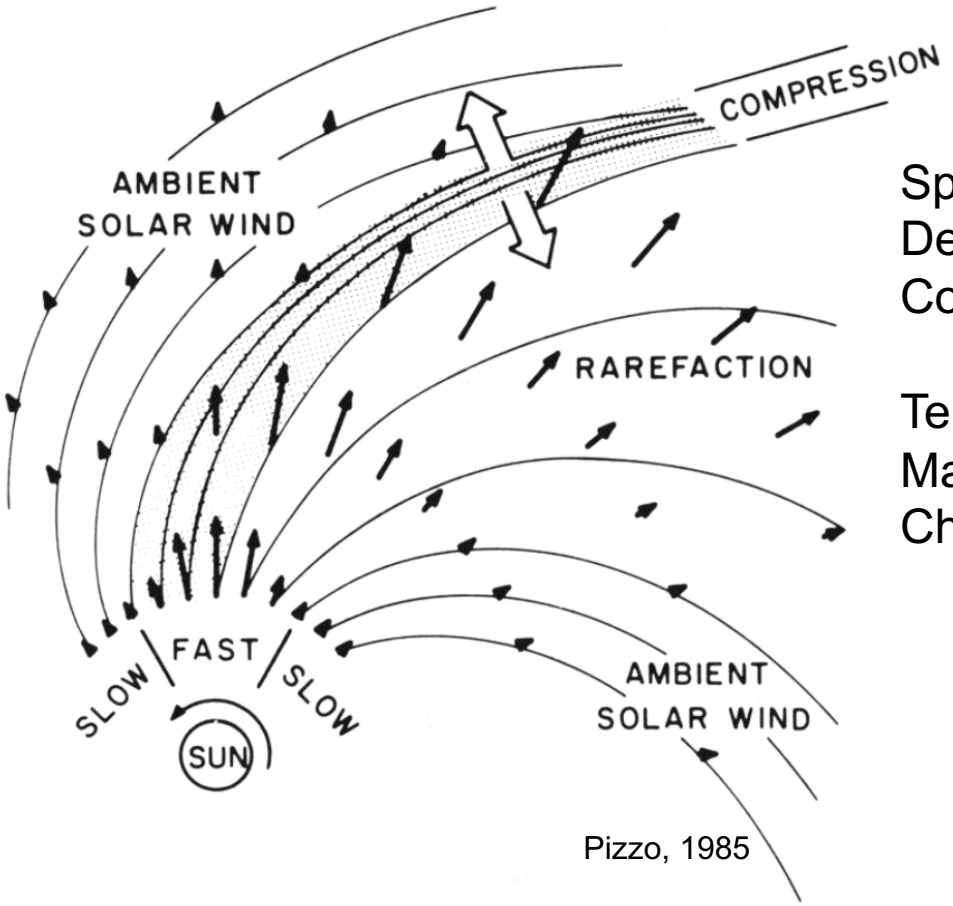
Theory



PFSS Magnetic Field Model

All of these features are related, yet a one-to-one mapping between features has never been successful.

The Fast Solar Wind



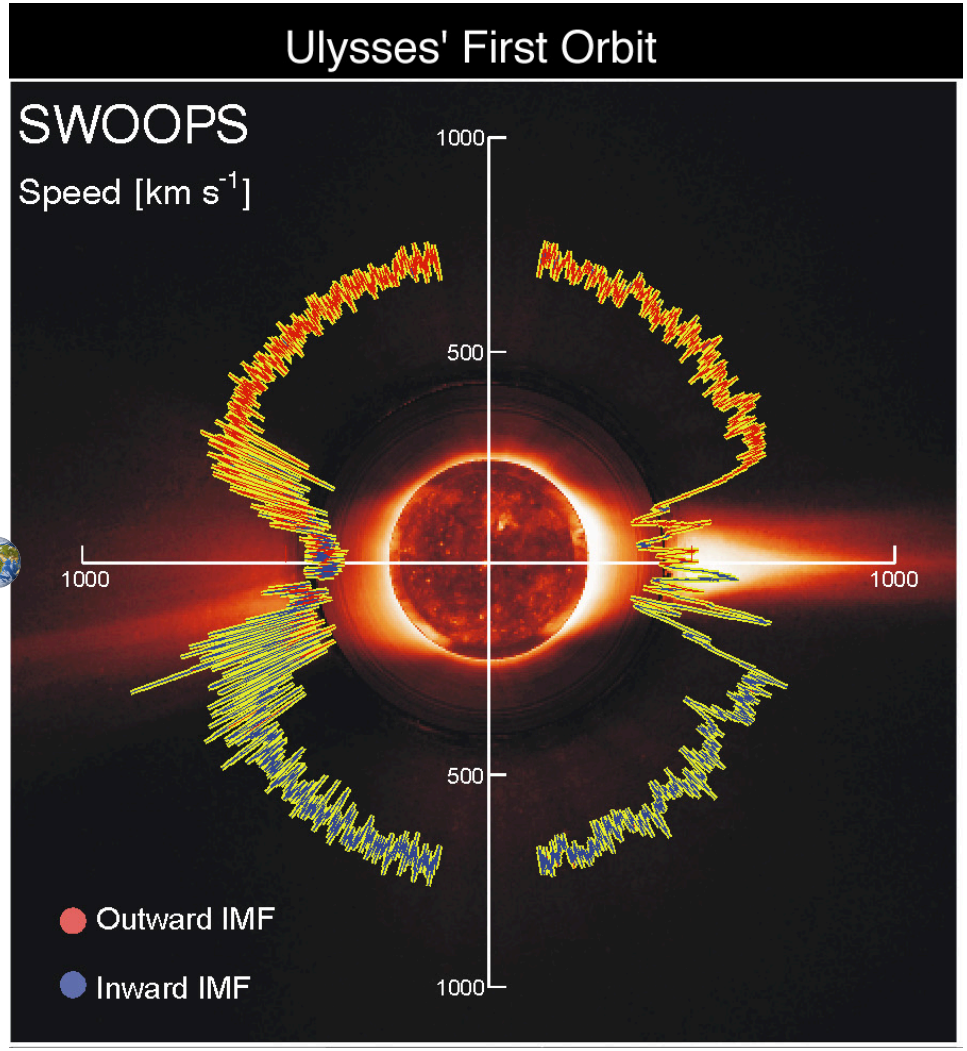
Pizzo, 1985

Speed:	400 – 800 km s^{-1}
Density:	n_p ~ 3 cm^{-3}
Composition:	~ 95% H; 5% He; some ion
Temperature:	T_p ~ 2 × 10^5 K
Magnetic Field:	~ 5 nT
Characteristics:	Alfvénic (EM) fluctuations

Origin In Coronal Holes

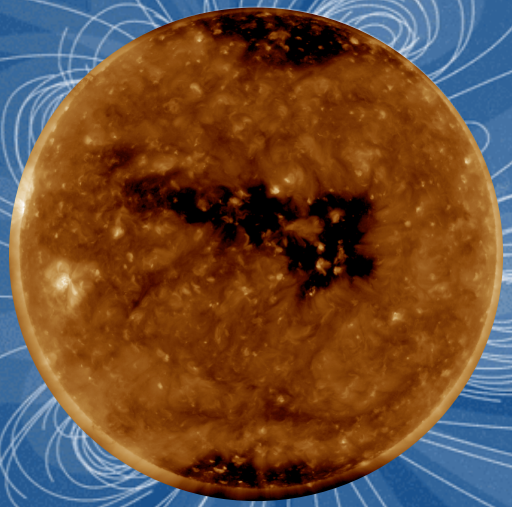
(Bothmer and Zhukov, 2007)

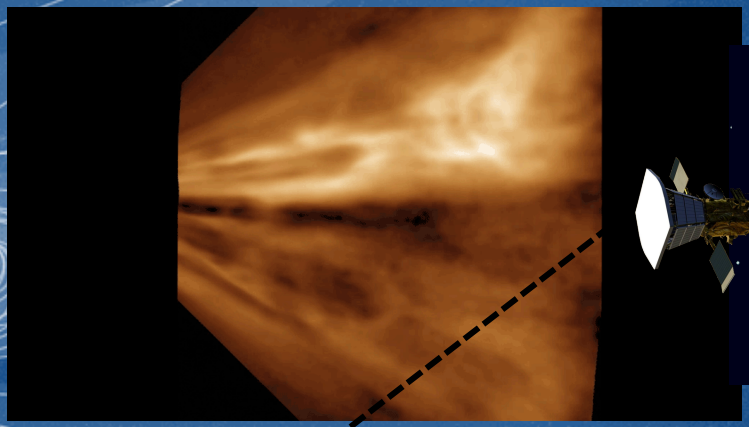
Coronal Holes and Space Weather

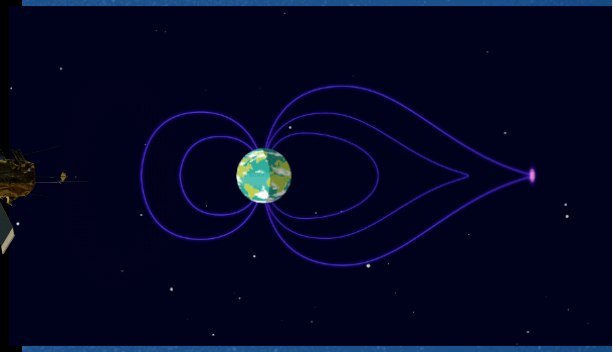


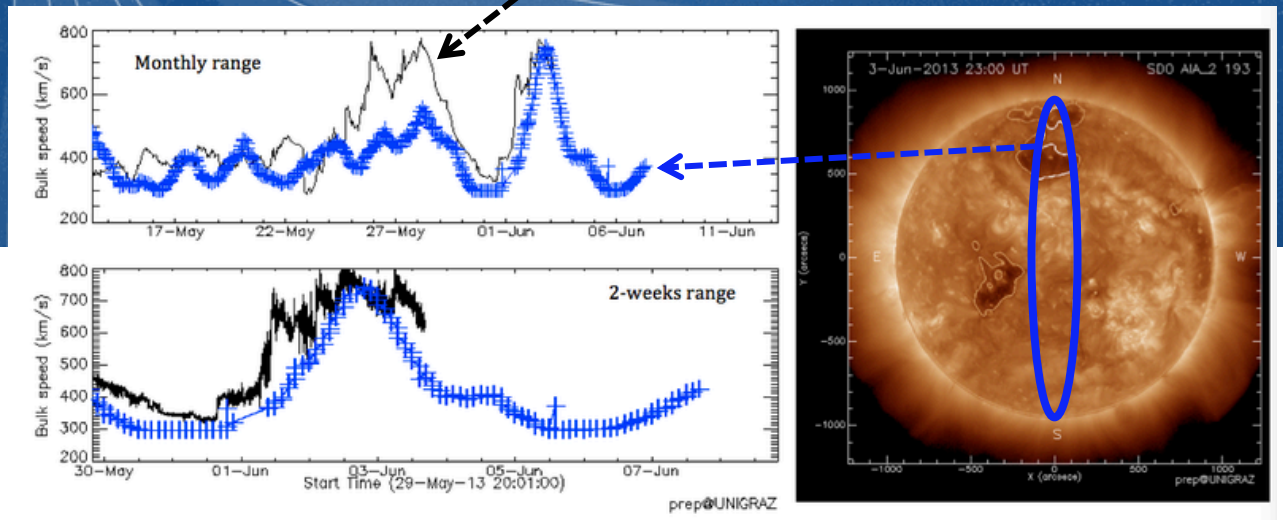
- Fast solar wind comes from coronal holes.
- Define the quiescent heliospheric environment.
- Direct connection to transition region plasma.

Coronal Holes and Space Weather



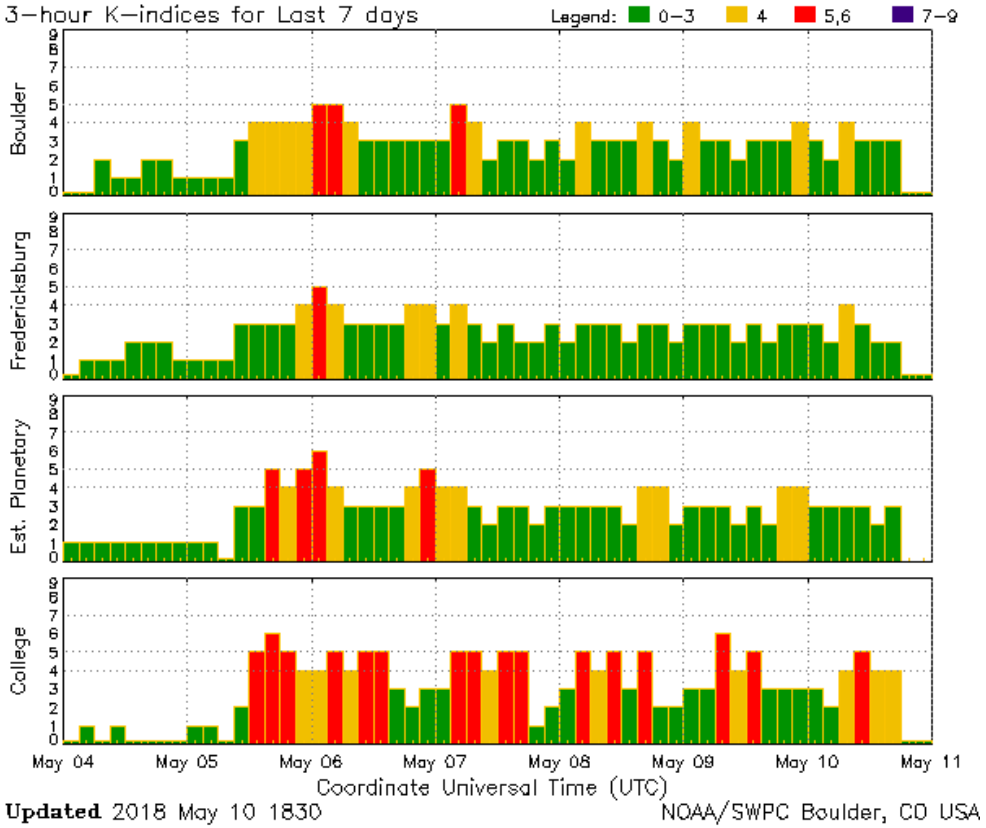




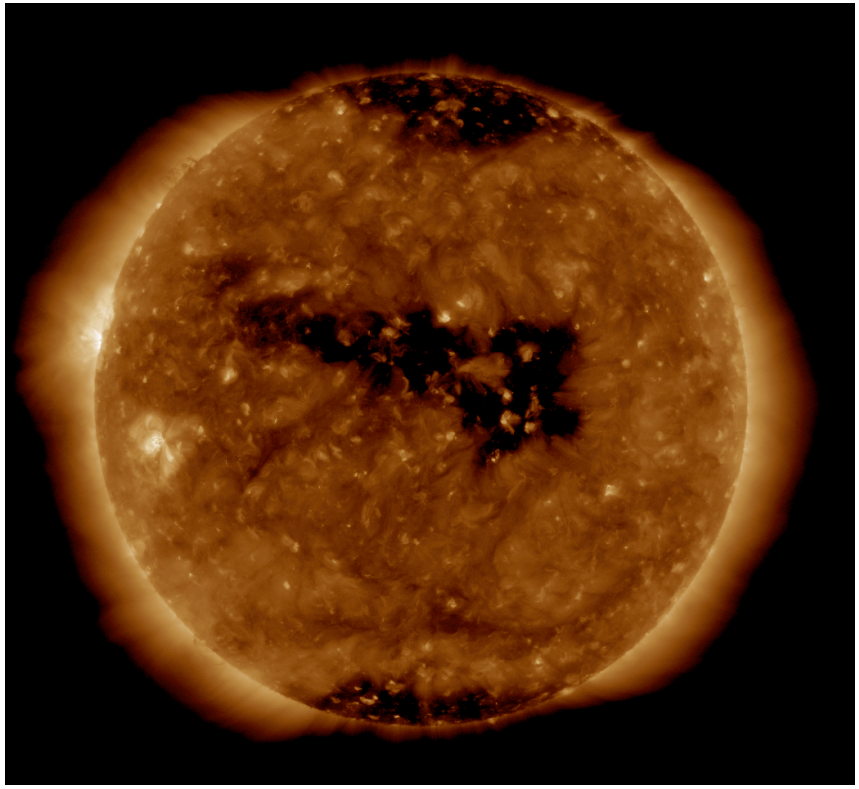


Coronal Holes to Earth

A high-speed stream can cause an energetic electron flux enhancement and magnetic field disturbances on Earth.



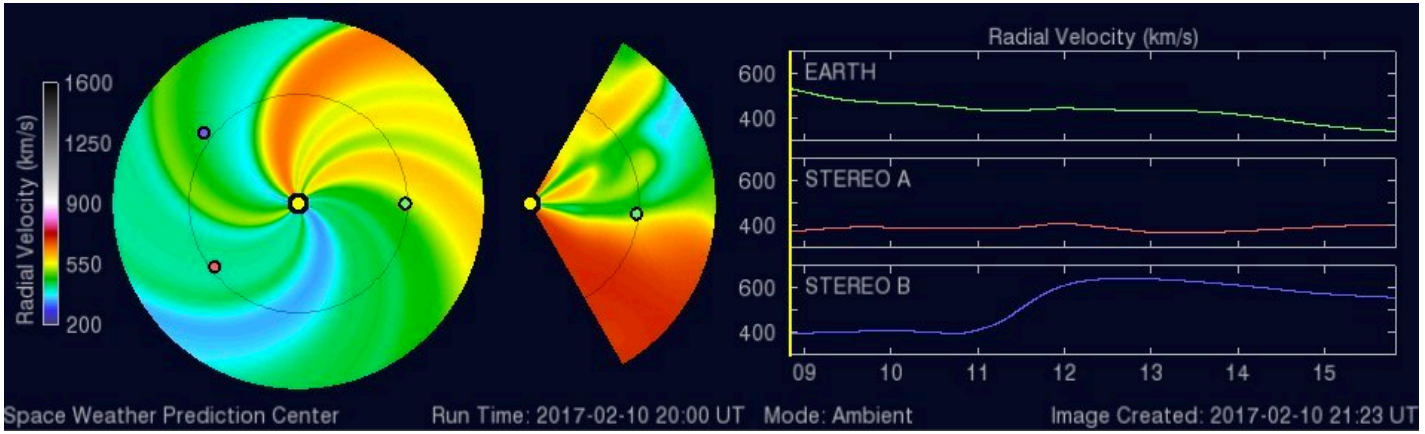
K-index quantifies disturbances in the horizontal component of earth's magnetic field



AIA 193Å | May 4, 2018

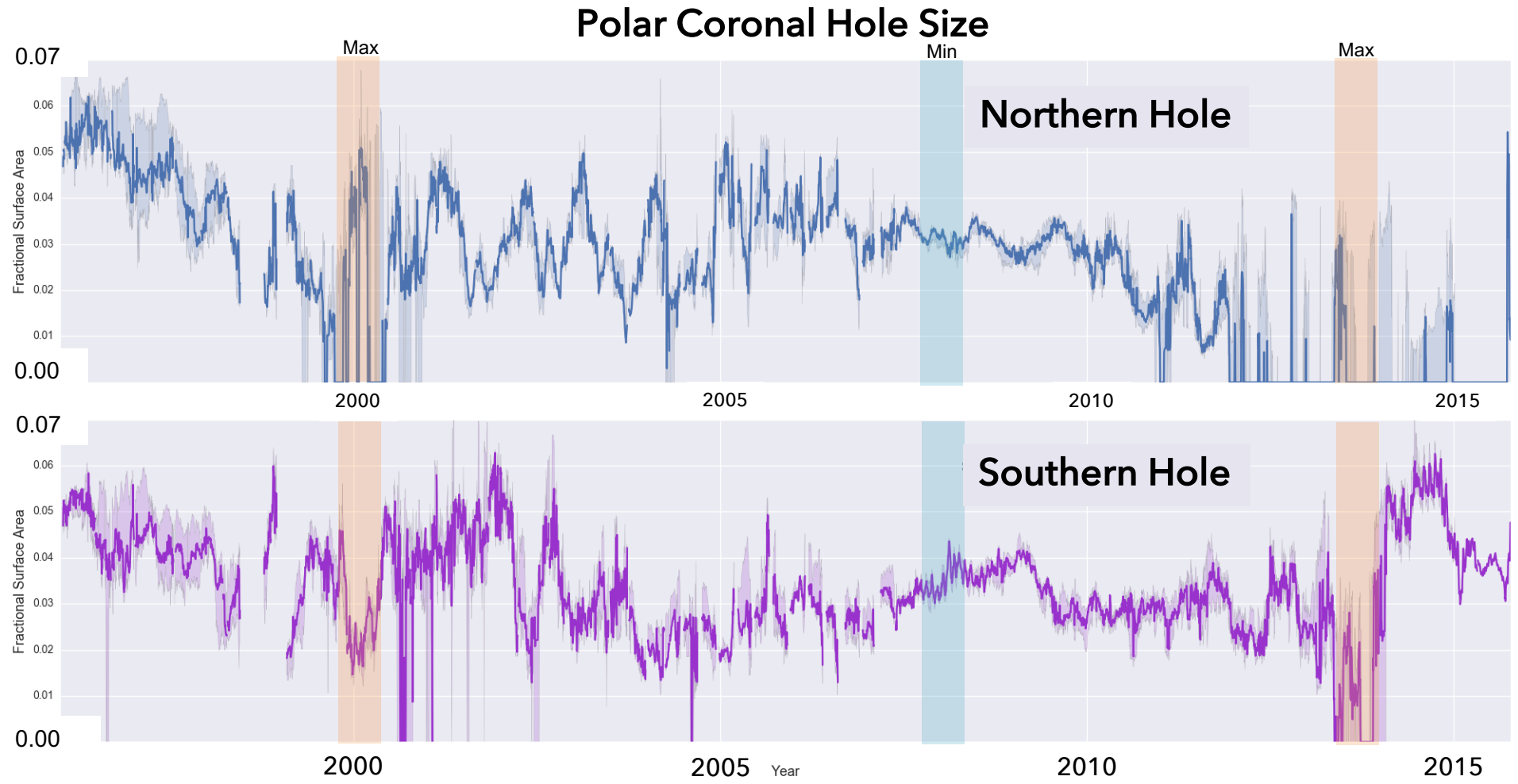
Hole Measurements, what are they good for?

- Current forecasts are highly dependent on coronal hole size and location (ENLIL, ADAPT).
- Geoeffective impacts of equatorial holes and CMEs are embedded in the quiescent solar wind
- A solar cycle measurement that is not activity dependent.
- Measurements of the global rearrangement of magnetic field at solar minimum.



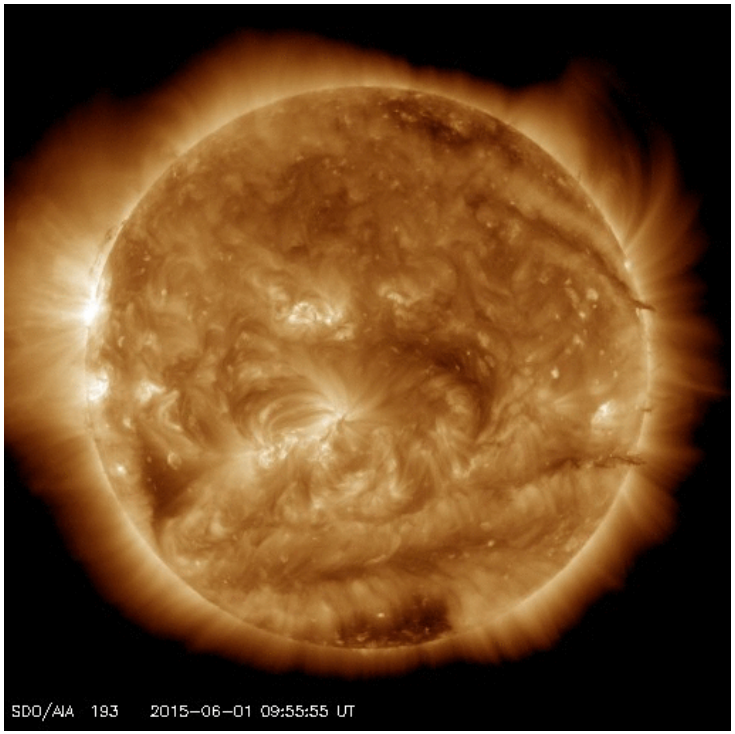
WSA-ENLIL Solar Wind Prediction

Evolution of the Holes

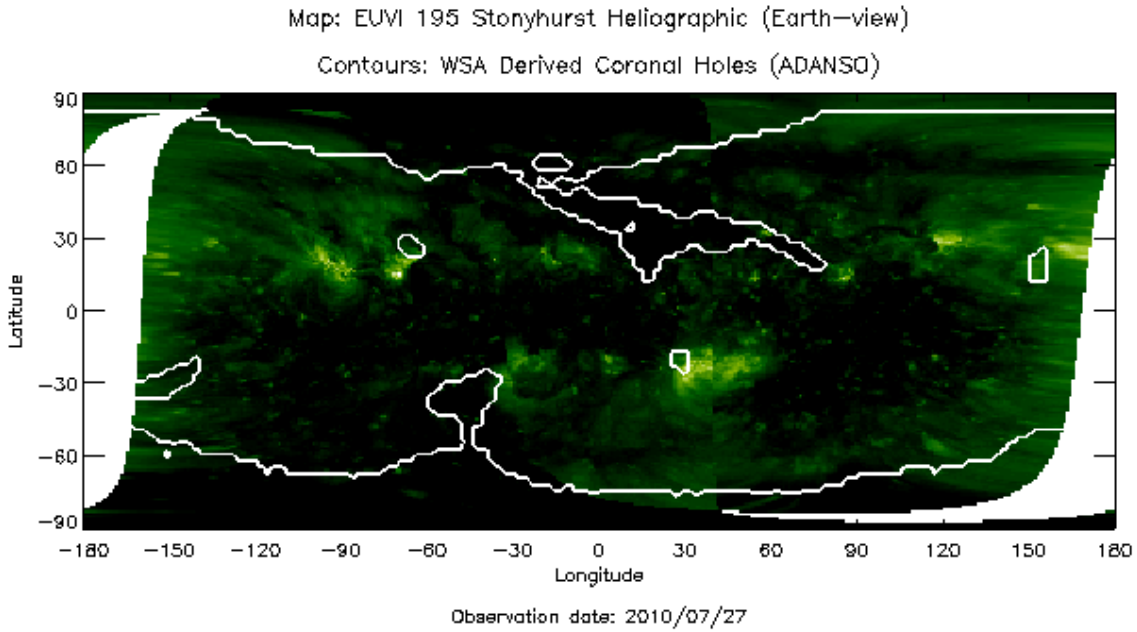


Kirk et al. 2017

Current Measurement Techniques



Kirk et al. 2009

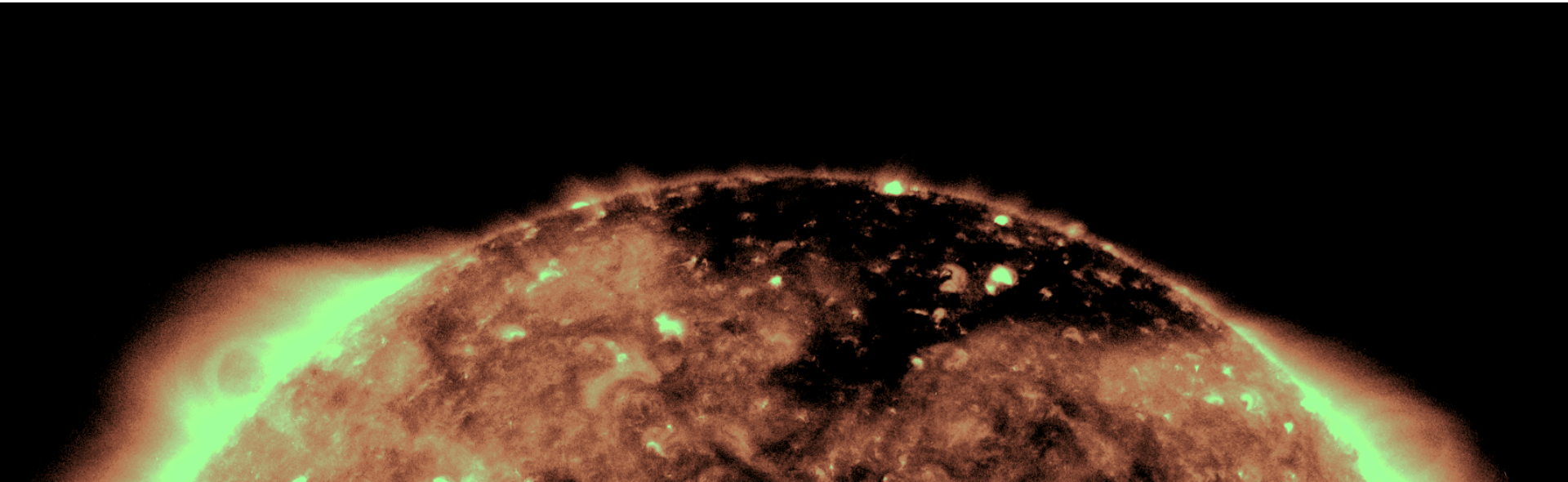


Arge et al. 2017

Examples of automated techniques for identifying coronal hole boundaries.

Coronal Holes: A Summary

- Regions of low emission in x-ray and EUV images.
  - Characterized as regions of *open* magnetic field lines.
    - The primary source of the fast solar wind.



Want to know more?

Living Solar Review on Coronal Holes: https://link.springer.com/article/10.12942/lrsp-2009-3

…or michael.s.kirk@nasa.gov

(and various other methods: slack, riot.im, twitter, skype, facebook, google hangouts, WhatsApp, dialing a phone, etc.…)

SunPy
A Community Python Library for Solar Physics